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September 30, 1998

Dear Michael,

Attached is the final report for the JSEP fellowship student Eric Mozdy. Summary statements from the advisor, Prof. Pollock, and the student are attached. He graduated in May 1998 and is currently employed at Corning Inc. in New York. Cornell University very much appreciates this generous fellowship support from AFOSR.

Yours sincerely,

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Dr Mozdy produced many quality publications in his two years as a JSEP Fellow. He made significant advances in the experimental observation of chaotic systems, he interacted with colleagues at Rome Labs and at Phillips Labs, and he has subsequently gone to work for a leading US manufacturer of optical components.

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Statement by Thesis Advisor

Final Research Report: September 30, 1998

Eric Mozdy completed his graduate studies in May, 1998. He defended his thesis, "Chaos in the additive-pulse mode-locked laser" and accepted a position at Corning, Inc., Corning, New York as a Research Scientist in fiber optic devices starting in June, 1998.

Dr. Mozdy's research advanced the experimental knowledge of chaotic lasers. Previous to his becoming a JSEP Fellow, he developed a rigourous model of a Chaotic laser which he used to simulate various dynamics of an additive-pulsed Mode-locked laser. This was described in his Master's thesis and was published in Discrete Dynamics in Nature and Society [1].

His PhD work involved experimental verification of his model, and exploration of the chaotic operation of a mode-locked laser. In his work he observed the first Experimental bifurcation plot of the additive-pulse mode-locked system. In his simulations he found that the non-linearity introduced by the optical fiber in the additive-pulse mode-locked laser had a strong effect on the chaotic orbit of the pulse-to-pulse laser operation. By adjusting the coupling strength to the fiber, it was possible to drive the laser from one chaotic orbit to the next. Scanning the fiber coupling allowed Eric to observe a significant portion of the bifurcation diagram for the system.

To achieve reliable operation, he first had to make the additive pulse laser operate reliably. He interacted with colleagues at Rome Laboratory, Griffis Air Force Base, NY to develop a method of mode-locking the laser using a saturable absorber [2]. He further extended this work by interacting with PI Prof. Yu-hwa Lo at Cornell to make an improved saturable absorber, which provided operation at a more useful wavelength and with greater power [3]. This work resulted in several publications [4].

Once the additive pulse laser was stable, he performed his chaos experiments. He not only was able to observe for the first time an experimental bifurcation diagram[5], but he also noticed a significant noise feature that would not go away[6]. After trying to eliminate this noise, he discovered it was due to a deterministic noise amplification caused by the chaotic orbits, This process was characterized and also published.

In summary, Dr. Mozdy produced many quality publications in his two years as a JSEP Fellow. He made significant advances in the experimental observation of chaotic systems, he interacted with colleagues at Rome Labs and at Phillips Labs, and he has subsequently gone to work for a leading US manufacturer of optical components.

1. E. J. Mozdy and C. R. Pollock, "Nonlinear dynamics of the additive-pulse mode-locked laser," Discrete Dynamics in Nature and Society (January 1998)

2. Martin A. Jaspan, Eric J. Mozdy, Clifford R. Pollock, Michael J. Hayduk, and Mark F. Krol, "Saturable Bragg Reflector Mode-locked NaCl:OH- Color Center Laser," IEICE Trans. Electron. Vol. E81-C, February 1998, pp.125-128

3. E. J. Mozdy, M. A. Jaspan, Zuhua Zu, Yu-Hwa Lo, and C. R. Pollock, R. Bhat, and Minghwei Hong, "NaCl:OH- Color Center Laser Mode-locked by a Novel Bonded Saturable Bragg Reflector," Accepted for publication in Optics Communication, April 1998

4. E. J. Mozdy and C. R. Pollock, "Self-starting of an additive-pulse mode-locked laser using a novel bonded saturable Bragg reflector," IEE Electronics Letters, vol. 34, pp. 1497 (1998)

5. E. J. Mozdy and C. R. Pollock, "Chaos in additive-pulse mode-locked lasers," submitted to Optics Letters (May, 1998)

6. E. J. Mozdy and C. R. Pollock, "Deterministic noise in the period-doubling bifurcation of an additive-pulse mode-locked laser," accepted in Physics Letters A (May 1998)

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Statement by Graduate Student

Thesis Title: CHAOS IN THE ADDITIVE-PULSE MODELOKED LASER

Thesis Abstract: The additive-pulse mode-locked (APM) laser has been traditionally used as an ultra-short pulsed light source, despite being hampered by multiple instabilities, including quasi-periodicity and chaos. Although the system is generally designed to avoid such instabilities, a detailed understanding of these nonlinear phenomena can serve to improve APM operation, as well as provide an excellent system for furthering current experimental chaos study. To this end, this thesis develops a model of the APM laser together with an experimental APM system, both of which display complicated nonlinear dynamics, including period-doubling bifurcations, chaos, and crisis behavior. The APM model is used to simulate the laser under conditions of high non-linearity, and to explore the dependencies of the dynamics on different APM parameters: fiber length, fiber coupling, and gain. The chaotic regions of operation are characterized by embedding dimension and largest Lyapunov exponent, and some chaotic attractors are plotted in three dimensions. The experimental APM laser system is then developed, optimized with the help of the model, and significant improvements are incorporated to allow experimental observation of detailed chaotic behavior. Saturable Bragg reflector mode-locking is demonstrated as a useful starting mechanism for the APM laser, and experimental results are presented. Random noise contributions are also considered in both the APM model and experiment, to allow for realistic comparison. The theoretical and experimental results are then compared graphically, indicating excellent agreement. Further data analysis techniques for confirming the existence of chaos are additionally implemented to strengthen the conclusions. Demonstration of the period-doubling route to chaos, Lyapunov exponent and correlation coefficient quantification of the chaos, and the excellent correlation between theory and experiment all represent new accomplishments and valuable insight into the APM laser dynamics.

Eric John Mozdy, PhD,
Cornell University, May 1998